(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 814 279 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
29.12.1997 Bulletin 1997/52

(51) Int. Cl.[6]: F16F 15/027

(21) Application number: 97110230.6

(22) Date of filing: 23.06.1997

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE

(30) Priority: 21.06.1996 JP 181473/96

(71) Applicant: EBARA CORPORATION
Ohta-ku, Tokyo (JP)

(72) Inventors:
- Haga, Takahide
Kawasaki-shi, Kanagawa-ken (JP)
- Watanabe, Katsuhide
Fujisawa-shi, Kanagawa-ken (JP)

(74) Representative:
Wagner, Karl H., Dipl.-Ing. et al
WAGNER & GEYER
Patentanwälte
Gewürzmühlstrasse 5
80538 München (DE)

(54) Vibration cancellation apparatus

(57) The object of the present invention is to provide a compact vibration cancellation apparatus based on a combination of air springs (11) and electromagnetic actuators (12) with smaller power capacity to enable the anti-vibration table (10) to be maintained in a level position even when the gravity of the anti-vibration table (10) moves over a large distance caused by a movement of the objective equipment (A) on the table.

A vibration cancellation apparatus for isolating floor vibration or canceling vibration of the objective equipment (A) on a anti-vibration table (10) comprises: at least three displacement sensors (12), acceleration sensors (13), levitation position control means, vibration canceling control means, and air spring actuators (11) for supporting four corners of said anti-vibration table (10) by air pressure; wherein said air pressure in each of said air spring actuator (11) is controlled in response to a change of load weight which corresponds to a movement of gravity caused by movement of said objective equipment (A) on said anti-vibration table (10).

Printed by Xerox (UK) Business Services
2.15.4/3.4

Description

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates in general to vibration cancellation apparatus for isolating floor vibrations or canceling vibrations of the objective equipment thereon to affect the production yield or measurement precision thereof such as semiconductor fabrication devices and electron-microscopes. Particularly the invention relates to a vibration cancellation apparatus that provides a combined action of air springs and electromagnetic actuators, in which vertical support of load weights is primarily provided by air spring actuators, and fine control of vibrations is primarily provided by electromagnetic actuators.

Description of the Related Art

Conventionally, vibration-sensitive equipment, such as electron-microscopes and semiconductor fabrication equipments whose performances are adversely affected by vibrations, have been installed on the floor, by way of some vibration isolation apparatuses such as air springs and rubber sheets. Replacing the conventional air springs and rubber-based arrangements as vibration isolation devices, high performance vibration cancellation apparatuses based on magnetic levitation have been developed.

Also a combination of air springs and electromagnetic actuator is known for isolating floor vibrations and canceling vibrations of the objective equipment on a anti-vibration table. According to these apparatuses, both air springs and electromagnetic actuators are used to actively control levitating positions and canceling vibrations in vertical direction. The objective equipment is supported on an anti-vibration table whose four corners are supported by actuators comprising air springs and electromagnetic actuators. Three proximity sensors and three accelerometers are used to detect table displacements and accelerations, and responding actions are applied quickly through digital controllers to the neumatic actuators and the electromagnetic actuators.

In reviewing the existing techniques of canceling vibration control, based on a combination of air springs and electromagnetic actuators, when the gravity of the table moves by movement of the objective equipment placed on the anti-vibration table over a large distance, two methods of leveling the anti-vibration table may be considered:

(1) To control the air pressures of the air springs actuators for leveling the table, or
(2) To control the vertical positions of the table by operating the electromagnetic actuators for leveling the table.

However, these approaches present the following problems.

(1) Because of the slow response characteristics of air springs actuators, when the gravity of the table moves at high velocities, they are not able to respond in a timely manners to keep the anti-vibration table level; and
(2) Although electromagnetic actuators are able to respond quickly for keeping the anti-vibration table level, it is necessary to increase the capacity of the electromagnetic actuators such that one of actuators can deal with the maximum anticipated load weight of the objective equipment, including the weight of the table. Because, when the gravity of the objective equipment moves to a corner of the table, then one of the electromagnetic actuator must support all of the weight for keeping the table level. Problems with this approach cause that the system cost becomes high and the system size becomes large.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a compact vibration cancellation apparatus based on a combination of air springs and electromagnetic actuators with smaller power capacity to enable the anti-vibration table to be maintained in a level position even when the gravity of the anti-vibration table moves over a large distance caused by a movement of the objective equipment on the table.

According to the present invention, there is provided a vibration cancellation apparatus, comprising, at least three displacement sensors for detecting vertical positions and outputting displacement signals; acceleration sensors for detecting vertical accelerations of said anti-vibration table and outputting acceleration signals; levitation position control means for said electromagnetic actuators according to first compensation circuit output signals based on displacement signals from said displacement sensors, vibration canceling control means for said electromagnetic actuators according to second compensation circuit output signal based on acceleration signals from said acceleration sensors; and air spring actuators for supporting four corners of said anti-vibration table by air pressure, said air pressure of each air spring actuator being independently adjustable by air pressure control means respectively; wherein said air pressure in each of said air spring actuator is controlled in response to a change of load weight which corresponds to a movement of gravity caused by movement of said objective equipment on said anti-vibration table.

Accordingly, actions for maintaining the table level are provided by two separate control actions: one to control the electromagnetic actuators for the normal levitated position control of the table sensed by the displacement sensors; and another to control the air spring

actuators for the air pressure to maintain the table level.

According to the present invention, there is also provided a vibration cancellation apparatus according to claim 1, wherein said air pressures for said air spring actuators are adjusted according to position signals of said objective equipment on said anti-vibration table, and said position signals are converted to said air pressure signals by feed forward controller.

According to the present invention, there is also provided a vibration cancellation apparatus according to claim 1, wherein said acceleration sensors are installed in a location different from said electromagnetic actuators, and control means are used to convert detected signal into equivalent action point signal for controlling said electromagnetic actuators at the action-points.

The above and other objects, features, and advantages of the present invention will become apparent from the following description when taken in conjunction with the accompanying drawings which illustrate a preferred embodiment of the present invention by way of example.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic elevation view of a vibration cancellation apparatus with a anti-vibration table having neumatic actuators and electromagnetic actuators.

Figure 2 is a schematic block diagram of a first embodiment of the anti-vibration system.

Figure 3 is a detailed representation of the control circuits for the system in the first embodiment..

Figure 4 is a schematic block diagram of a second embodiment of the anti-vibration system.

Figure 5 is a detailed representation of the control circuits for the system in the second embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

As shown in Figure 1, the vibration cancellation apparatus comprises an anti-vibration table 10, air spring actuators 11, electromagnetic actuators 12, acceleration sensors 13 and so on. The anti-vibration table 10 is for placing an objective equipment A which is such equipment A as electron microscope or semiconductor fabrication apparatus. The table 10 is supported at its four corners with air springs 11 operative in the vertical direction. The bottom ends of the air springs 11 are fixed on a common base 14 which is fixed to the installation floor. Acceleration sensors (hereinbelow referred to as accelerometers) 13 are disposed on the lower side of the table 10 for detecting the acceleration of the table in vertical detection.

As shown in Figure 2, air springs 11A, 11B, 11C and 11D supports the four corners of the table 10. Three electromagnetic actuators 12A, 12B and 12C are placed in a different location from the locations of the accelerometers 13A, 13B and 13C which are active in the vertical direction. A displacement sensor is provided within each of the electromagnetic actuators 12A, 12B and 12C for detecting the displacement of the table in vertical direction.

The control method for isolating floor vibrations and canceling vibrations of the objective equipment will be described as follows with reference to Figures 2 and 3. Displacement signals generated by the displacement sensors in each of the electromagnetic actuators 12A, 12B and 12C are forwarded to a controller section 20 and are compared with target levitation positions (normal levitation position without vibrations). The difference between the target values and the current values are compared by the comparator 21, and the difference signal is forwarded to the position compensation device 22, which outputs a compensation signal so as to levitate the table 10 at the target position by the electromagnetic actuators. The compensation signal after being amplified in an electrical amplifier 23, is supplied to the respective coils of the electromagnetic actuators 12A, 12B and 12C.

The acceleration signals in the vertical direction detect by the accelerometers 13A~C are forwarded to the controller 20, and integrated in the integrator 25 to be converted to velocity signals. The velocity signals are multiplied by their respective gain coefficients Kvv to be compensation signals for canceling vibrations detected by the accellometers, and are added in the adder 24 to position compensation signals output from the position compensation device 22. These signals are amplified in the amplifier 23, and are supplied to the respective coils of the electromagnetic actuators 12A, 12B and 12C.

Position compensation signals outputted by position compensation device 22 based on the current positions of the table 10 in vertical direction are forwarded to pressure control devices for controlling air pressure of the air springs. The position compensation signals are forwarded to a control output distributor 31, and are converted to equivalent pressure control signals for the onsite air springs to levitate the table 10 at the target position are multiplied by a gain coefficient KAP and are added to the target pressure value in the adder 25. The air pressures in the springs 11A, 11B, 11C and 11D communicating with an air supply source are adjusted through a regulator 33 to correspond with the output signals of position compensation device 22. The table 10 is kept level in the target levitation position by adjustment in the air pressures, eventhough the load weight is changed at each air spring of four corners.

Therefore, when an objective equipment A, placed on the table 10, is stationary in a certain location near the center of the table 10, the applied load weight is supported primarily by the air springs 11A, 11B, 11C and 11D by setting the pressure at appropriate values, and the electromagnetic actuators 12A, 12B and 12C do not substantially take part in sharing the applied load weight. This condition represents the normal condition for these electromagnetic actuators, and any deviations from the normal condition caused by vibrations are sensed by the accelerometers, and are compensated

under the control of the controller section 20 (second compensation circuit).

When the objective equipment A moves over a large distance on the anti-vibration table 10, then the gravity of the table 10 moves at a distance causing a change of the load weight among the air springs 11A, 11B, 11C and 11D, and displacements in the vertical direction are changed among displacement sensors. At this time, so as to keep the table 10 in a normal level position, the control forces for leveling the table must be increased. The magnitude of the changes in the control forces appear as the output signals of the position compensation device 22 derived from displacement sensor signals, and they correspond to control force parameters for the air pressures in the air springs 11A, 11B, 11C and 11D. The output signals from the position compensation device 22 are used to alter the pressures in the air springs via transforming data between the positions of displacement sensors and air springs. Namely, the output signal of the position compensation device 21 is inputted to adder 25 via control output distributor 31. The air pressures are adjusted according to a changing situation of load weight by each of the air springs to keep the table 10 in a level position.

Therefore, even if the objective equipment A moves through a large distance and the gravity of the table 10 moves at a large distance, the required changes in the respective load weight from the normal condition are compensated together by the levitation position control action of the electromagnetic actuators and by the air pressure control action of the air springs. The levitation position control action by the electromagnetic actuators provides high speed and precise response for leveling the table, and the air pressure control action by the air springs provides no consumption of electric power to support substantially full load weights even though the response is slow. Therefore two kinds of control actions work complementatily with each other. In other words, even relatively low power capacity of electromagnetic actuators are sufficient to provide the necessary compensation currents for keeping the table 10 level when the gravity moves at a distance.

Figure 3 shows the details of a control circuit block diagram presented in Figure 2.

The acceleration values in the vertical direction of the table 10 detected by the accelerometers 13A, 13B and 13C, are different from the actual action points where the actuations are applied to. Therefore, the output values from the accelerometers 13A, 13B and 13C are inputted into acceleration point transformation device 29 transforming the acceleration value from the detected point to the action point.

The output signals from the acceleration point transformation device 29 for each of the electromagnetic actuators12A, 12B and 12C are inputted into respective controllers 20A, 20B and 20C for the electromagnetic actuators 12A, 12B and 12C. The output signals from the displacement sensors, housed in the electromagnetic actuators 12A, 12B and 12C, are also inputted into the corresponding control circuits 20A, 20B and 20C. The displacement signals are inputted into the respective adders 21A, 21B and 21C, and are compared with the target levitation values. The difference value between the target and current values are inputted into in the individual position compensation device 22A, 22B and 22C. Their output signals are inputted into the adders 24A, 24B and 24C for the electromagnetic actuators, as well as to the control output distributor 31 of the pressure control device for the air springs.

Like as in the case of the acceleration point transformation device 29, because of the difference in the respective points between the measuring sensors and on-site air actuators of the air springs, the control output distributor 31 is used to convert the measured displacement signals to actuation-point control signals required by the air actuators. In the adders 24A, 24B and 24C, vibration compensation signals (which is computed by integrating the acceleration signals from the accelerometers and multiplying the integration result by a coefficient Kvv) are added to position compensation signals from the displacement sensors. The added results (signals) are amplified in the respective amplifiers 23A, 23B and 23C, and are supplied as excitation current to the windings of the respective electromagnetic actuators 12A, 12B and 12C. The result is that the electromagnetic actuators 12A, 12B and 12C perform high precision vibration canceling control as well as keeping levitation position of the table 10 to its target position with high speed response.

In the meantime, the compensation signals for the air springs, based on the displacement signals from the displacement sensors, are multiplied with a coefficient K_{AP} after the control output distributor 31 and are inputted into the adders 25A, 25B, 25C and 25D, where they are added on the target values of the air pressure settings, and the regulator valves 33A, 33B, 33C and 33D of the regulator 33 are adjusted according to the results of the added process.

The air pressures supplied from the air pressure supply source are thus adjusted and applied to each of the air springs 11A, 11B, 11C and 11D, so that, even if the load weight for the air springs is changed, the table 10 can be maintained level. The position adjustment action by air pressure control is a comparatively slow response, but the electromagnetic actuators have already been used to provide high speed compensation to the changes in the levitation forces so that the overall system response is quite superior to any results obtained by the conventional schemes for leveling compensation.

Figures 4 and 5 show outline of the control system of a second embodiment and its detailed circuit configuration, respectively. Vibration-sensitive objective equipment is placed on the anti-vibration table which is supported in the vertical direction at its four corners with air springs 11 and rapid position adjustment is provided by electromagnetic actuators as in the first embodiment. The anti-vibration table 10 is similarly provided with

accelerometers, and canceling vibration control is provided by the electromagnetic actuators as in the first embodiment. The displacement signals generated by the displacement sensors housed in the electromagnetic actuators are inputted to the position compensation device 22, and are supplied as excitation current to the coils of the electromagnetic actuators through power amplifiers 23 to adjust the levitation position of the anti-vibration table so as to keep the table level.

Also, air pressure control mechanism is the same, by using the air springs 11A, 11B, 11C, and 11D disposed at four corners of the table 10 to support load the weight of the table including objective equipment, and adjustment in the air pressures is used to maintain level position of the table. The difference in the second embodiment is that an objective equipment location controller 35 is provided on the table 10 to control the planar position of the objective equipment A. This controller 35 is a controller such as using an X-Y stage on the table, for example, for moving the objective equipment A in orthogonal directions, and producing X-position signals and Y position signals according to the moving position of the objective equipment A in the X- and Y directions. The command signals for moving the object A is generated by the controller 35 and are forwarded to the air pressure control device 36. The values of the air pressures necessary for maintaining the table 10 level are computed by the feed forward (FF) control device 36, and these values are added to the pressure settings and the pressures in the air springs are adjusted through the regulator 33.

Therefore, even if the objective equipment A is moved at some distance, this movement signal is outputted by the objective equipment location controller 35 and the on-site compensation of air pressures to correspond with the amount of gravity movement are computed by the feed forward (FF) compensation device 36, and the air pressures in the air springs are adjusted accordingly. The air pressures are adjusted according to compensate the change of load weight in the air springs, and the table 10 is maintained level. Also, if the table 10 is moved at a distance, the displacement sensors housed in each of the electromagnetic actuators 12A, 12B and 12C detect the vertical displacement values. The action-point values for the electromagnetic actuators 12A, 12B and 12C are computed by position compensation device 22, and are supplied as excitation currents to the coils of the actuators to keep the table 10 rapidly to the normal levitation position. By using the combined controls of electromagnetic actuator adjustments based on displacement signals together with air pressure adjustments in the air springs, the levitation position adjustments by the electromagnetic actuators can be carried out very rapidly while the level maintenance action by the air springs can be carried out without consuming electric power. The overall response of the system is quite good, and leveling the table can be carried out with high speed response by the electromagnetic actuators and without increasing the consumption of the electrical power by the air springs. Therefore, even if the center of gravity of the table is moved over a large distance by moving the object A, the anti-vibration table can be kept in a level position without increasing the electrical capacity of the electromagnetic actuators.

It should be noted that the canceling vibration control process was illustrated by a feedback process of integrating the acceleration signals and multiplying the integral by a gain coefficient, however, it is also possible to further add the acceleration signals for feedback of total sum data. Also, three electromagnetic actuators and accelerometers were used in the embodiment, but any number of such devices may be used depending on the need of the system.

It has been demonstrated that by utilizing either the output signals from the compensation circuit based on the displacement sensor signals for levitation position control of the anti-vibration table housed in accelerometers, or the output signals from the FF compensation circuit based on the planar position signals for the objective equipment placed on the anti-vibration table, it is possible to adjust the air pressures in the air springs supporting the corners of the anti-vibration table. Therefore, even if the center of gravity of the objective equipment on the table move over a large distance, the table is held approximately in the target level position. Therefore, the electromagnetic actuators are used primarily to provide rapid restoration of the anti-vibration table to the target levitation position, and to provide anti-vibration control actions based on acceleration data, so that the capacity of electromagnets needed to perform overall vibration control does not have to be increased excessively.

Although a certain preferred embodiment of the present invention has been shown and described in detail, it should be understood that various changes and modifications may be made therein without departing from the scope of the appended claims.

According to its broadest aspect the invention relates to a vibration cancellation apparatus for a anti-vibration table, comprising:

> displacement sensors for detecting vertical positions and outputting displacement signals;
> acceleration sensors for detecting vertical accelerations of said anti-vibration table and outputting acceleration signals; and
> levitation position control means; and
> a vibration cancellation apparatus for isolating floor vibration or canceling vibration of the objective equipment on a anti-vibration table, based on a combined action of air springs and electromagnetic actuators, comprising:
>
>> displacement sensors for detecting vertical positions and outputting displacement signals;
>> acceleration sensors for detecting vertical accelerations; and

vibration canceling control means.

Claims

1. A vibration cancellation apparatus for isolating floor vibration or canceling vibration of the objective equipment on a anti-vibration table, based on a combined action of air springs and electromagnetic actuators, comprising:

   at least three displacement sensors for detecting vertical positions and outputting displacement signals;
   acceleration sensors for detecting vertical accelerations of said anti-vibration table and outputting acceleration signals;
   levitation position control means for said electromagnetic actuators according to first compensation circuit output signals based on displacement signals from said displacement sensors,
   vibration canceling control means for said electromagnetic actuators according to second compensation circuit output signal based on acceleration signals from said acceleration sensors; and
   air spring actuators for supporting four corners of said anti-vibration table by air pressure, said air pressure of each air spring actuator being independently adjustable by air pressure control means respectively;
   wherein said air pressure in each of said air spring actuator is controlled in response to a change of load weight which corresponds to a movement of gravity caused by movement of said objective equipment on said anti-vibration table.

2. A vibration cancellation apparatus according to claim 1, wherein said output signals from said first compensation circuit based on displacement signals, are supplied to control output distributor, and converted to air pressure signals to each of said air spring pressure control means.

3. A vibration cancellation apparatus according to claim 1, wherein said air pressures for said air spring actuators are adjusted according to position signals of said objective equipment on said anti-vibration table, and said position signals are converted to said air pressure signals by feed forward controller.

4. A vibration cancellation apparatus according to claim 1, wherein said acceleration sensors are installed in a location different from said electromagnetic actuators, and control means are used to convert detected signals into equivalent action point signals for controlling said electromagnetic actuators at the action-points.

5. A vibration cancellation apparatus for a anti-vibration table, comprising:

   displacement sensors for detecting vertical positions and outputting displacement signals;
   acceleration sensors for detecting vertical accelerations of said anti-vibration table and outputting acceleration signals; and
   levitation position control means.

6. A vibration cancellation apparatus for isolating floor vibration or canceling vibration of the objective equipment on a anti-vibration table, based on a combined action of air springs and electromagnetic actuators, comprising:

   displacement sensors for detecting vertical positions and outputting displacement signals;
   acceleration sensors for detecting vertical accelerations; and
   vibration canceling control means.

FIG. 1

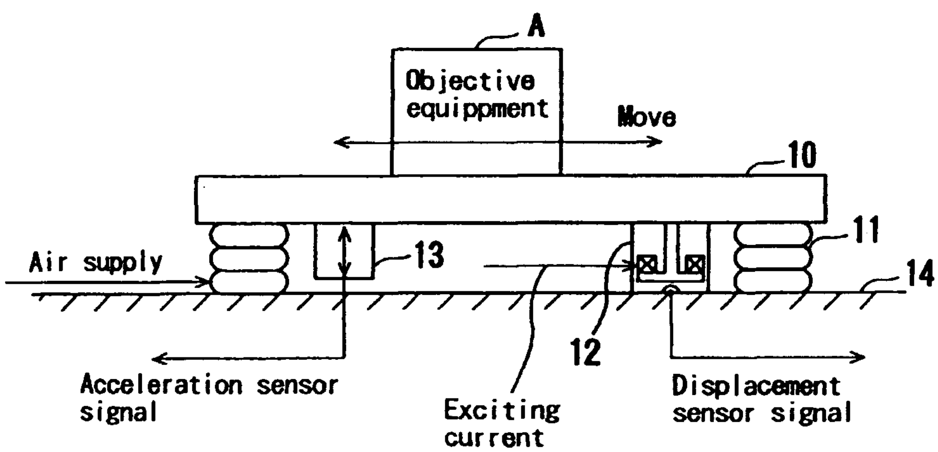
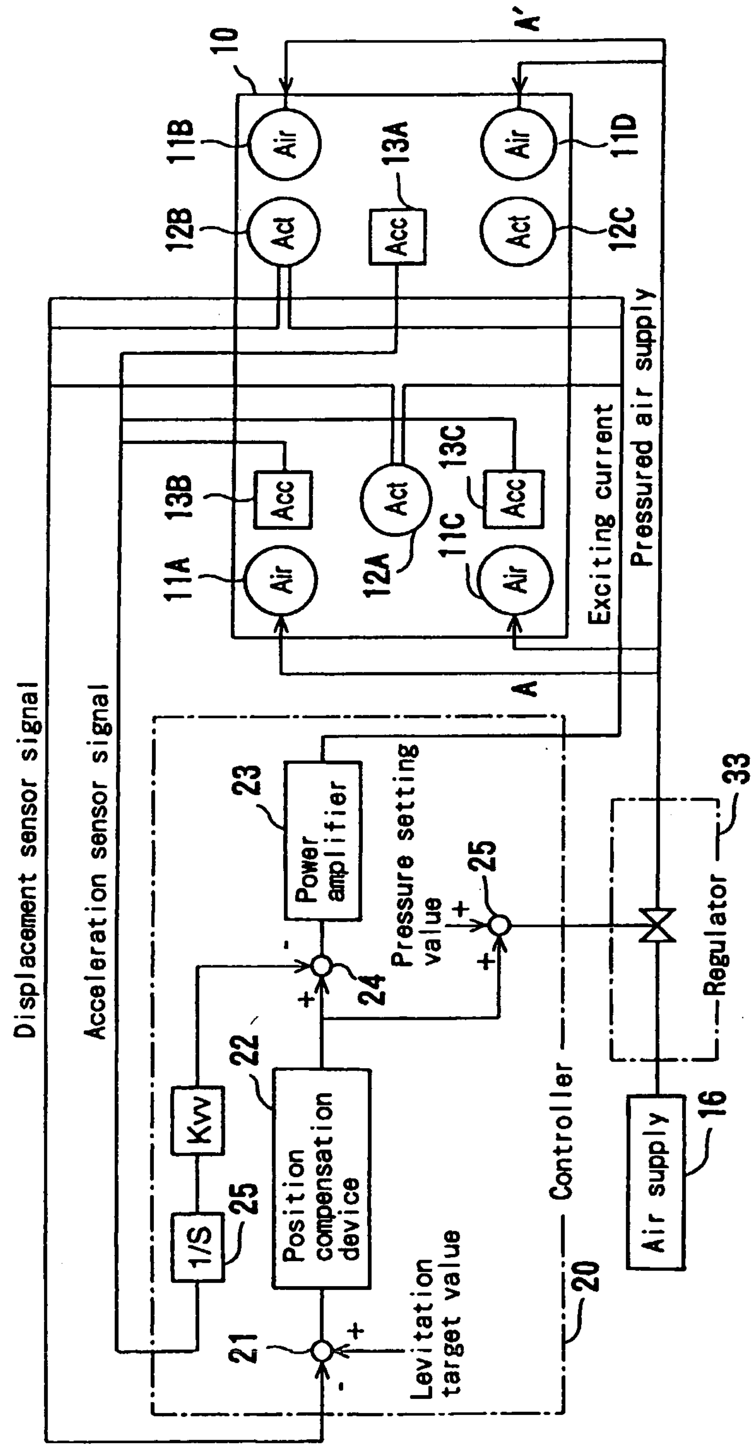

A
Objective equippment
Move
10
11
13
14
Air supply
12
Acceleration sensor signal
Exciting current
Displacement sensor signal

FIG. 2


10
11B
Air
12B
Act
13A
Acc
Air
11D
Act
12C
A'
11A
Air
13B
Acc
12A
Act
11C
13C
Acc
Air
Exciting current
Pressured air supply
A
Displacement sensor signal
Acceleration sensor signal
23
Power amplifier
Pressure setting value
25
+
+
-
+
24
22
Kvv
1/S
25
Position compensation device
21
+
-
Levitation target value
Controller
20
33
Regulator
Air supply
16

F I G. 3

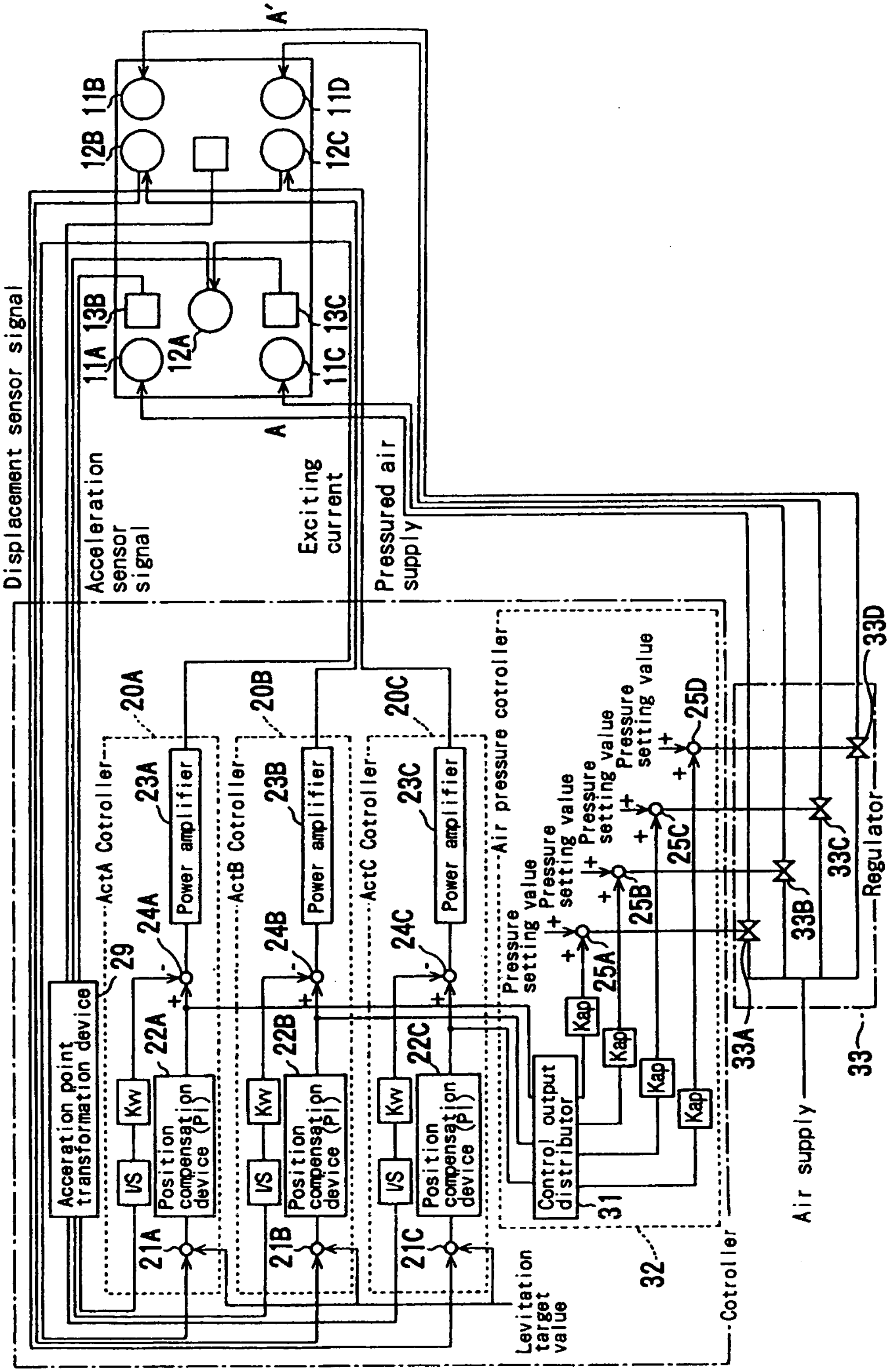
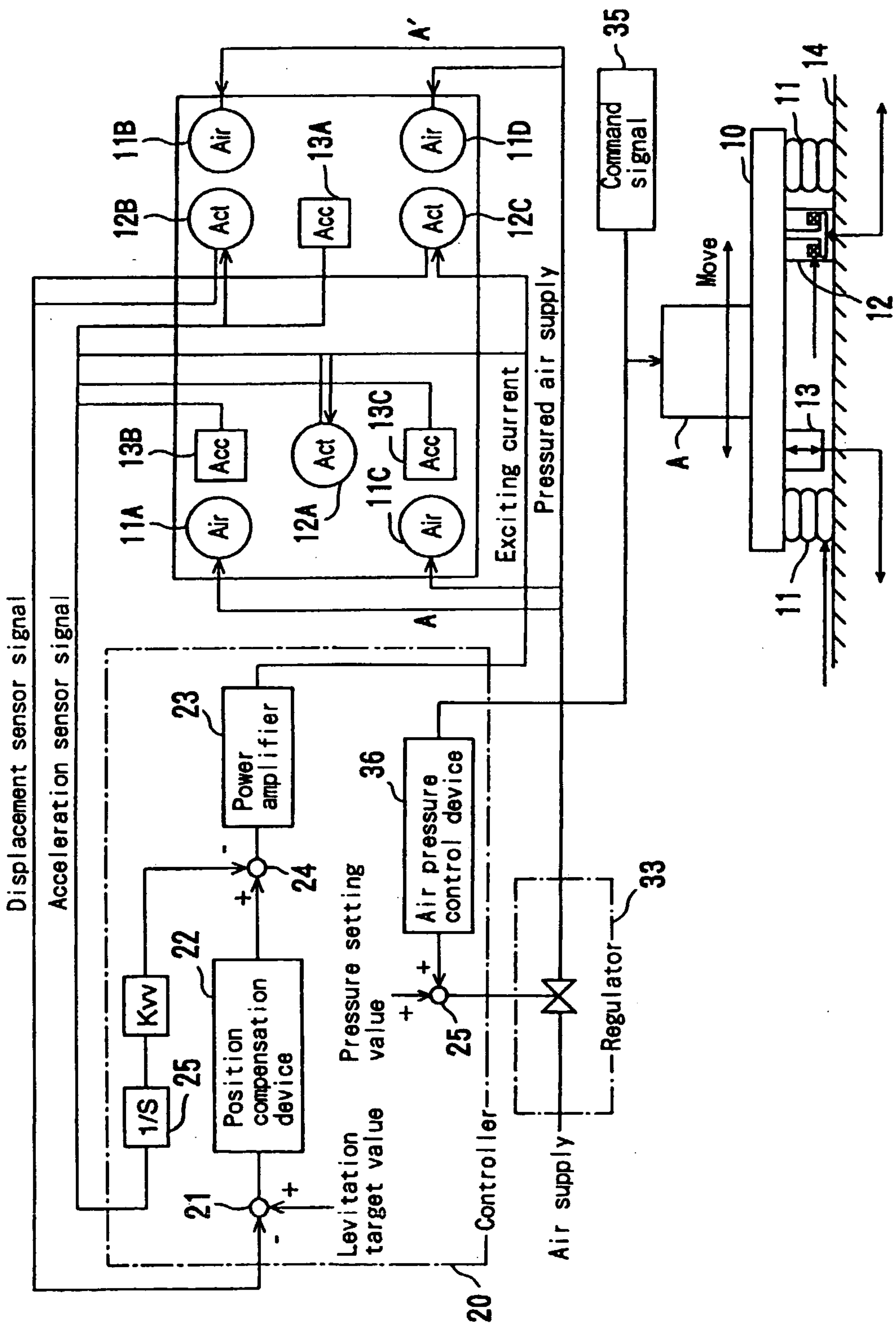

Displacement sensor signal
Acceleration sensor signal
Exciting current
Pressured air supply
A
A'
11A
13B
12A
11C
13C
12B
11B
12C
11D
20A
20B
20C
ActA Cotroller
ActB Cotroller
ActC Cotroller
Air pressure cotroller
Power amplifier
23A
23B
23C
24A
24B
24C
22A
22B
22C
21A
21B
21C
Kv
V/S
Position compensation device (PI)
Acceration point transformation device
29
Control output distributor
31
32
Kap
Pressure setting value
25A
25B
25C
25D
33A
33B
33C
33D
33
Regulator
Air supply
Levitation target value
Cotroller

FIG. 4


Displacement sensor signal
Acceleration sensor signal
Levitation target value
21
+
-
1/S
25
Kvv
Position compensation device
22
+
-
24
Power amplifier
23
Pressure setting value
+
+
25
Air pressure control device
36
Controller
20
Air supply
Regulator
33
Exciting current
Pressured air supply
A
A'
Air
11A
Acc
13B
Act
12A
11C
Air
Acc
13C
Act
12B
Air
11B
Acc
13A
Act
12C
Air
11D
Command signal
35
Move
A
10
11
11
12
13
14

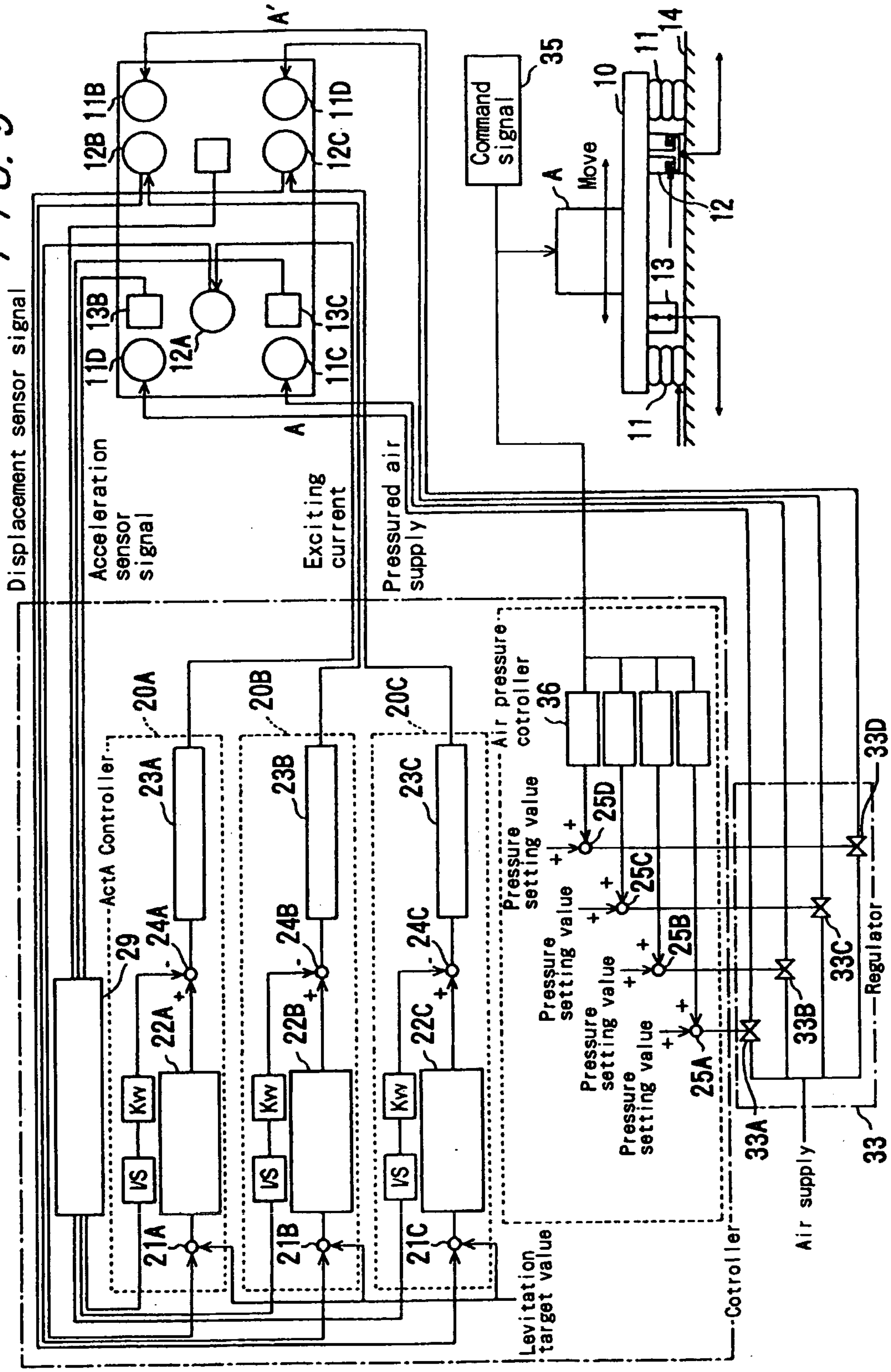

Displacement sensor signal
Acceleration sensor signal
Exciting current
Pressured air supply
12B 11B
12C 11D
11D 13B
12A
11C 13C
A
A'
Command signal
35
10
11
14
A
Move
12
13
11
ActA Controller
20A
20B
20C
23A
23B
23C
24A
24B
24C
22A
22B
22C
21A
21B
21C
Kv
VS
29
Air pressure cotroller
36
25D
25C
25B
25A
Pressure setting value
Pressure setting value
Pressure setting value
Pressure setting value
33A
33B
33C
33D
Regulator
33
Air supply
Levitation target value
Cotroller

FIG. 5